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Developing a Blended Computer Security Course

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Abstract – Online learning is expanding rapidly both for traditional student populations and for industrial and non-traditional student groups. This paper describes an experiment of migrating a computer security lecture course into a blended format, utilizing a combination of online and in-class delivery. The experiment was largely successful, but illuminated a number of factors to be considered in moving to an online format.

Index terms – Distance learning, online learning, computer security

I. Introduction

Distance and online learning is becoming increasingly prevalent at U.S. institutions of higher learning. A recent survey [1] by the Babson College Survey Research Group reports that:

- Over 6.1 million students were taking at least one online course during the fall 2010 term.
- This represents a 10% growth rate for online enrollments, which far exceeds the 1% growth of the overall higher education student population.
- Thirty-one percent of all higher education students now take at least one course online.

This suggests that online learning is coming whether or not institutions are ready for it.

For a university-level program or department to move to using online education requires attention to the ways in which online education differs and *should differ* from traditional lecture-based education. An extensive literature addresses this question (e.g., [2, 3]). However, most university faculty are experts in their field of knowledge, not in instructional design or pedagogy. How then can a program successfully introduce online instruction into an existing curriculum while preserving the integrity of their course offerings and using the new media to best effect?

In 2011, the College of Natural Sciences and the Department of Computer Science at the University of Texas at Austin supported migrating an existing traditional (face-to-face) lecture course, Introduction to Computer Security, into a blended format[1] using a combination of online and in-class instruction.

There were two primary goals driving this effort:

- investigate the benefits and challenges of using online instruction for delivering this content to CS majors;
- use the move to online delivery of the course as a first step toward developing an online security offering for IT industry professionals and non-traditional students.

In addition, there were three subsidiary constraints/goals for the effort:

- maintain the basic content and rigor of the existing lecture-based course as a credible component of the CS undergraduate curriculum at UT Austin;
- follow best practices in using online media effectively as a teaching tool;

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[1] Allen and Seaman [1] introduce the following taxonomy:

- *Online* refers to courses where most content (at least 80%) is delivered online.
- *Blended/Hybrid* refers to courses that combine online and face-to-face delivery, with 30% to 79% delivered online;.
- *Web-facilitated* denotes courses using web-based technology to facilitate what is essentially a face-to-face course, with 1% to 29% of content delivered on-line.
- *Traditional* means a course with no online delivery.

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- test the suitability of an existing content delivery system (the Quest Learning and Assessment system) for supporting a course of this type.

Note that these goals and constraints are not necessarily complementary. Delivering a credible, full-semester security course with challenging technical content suitable for a CS major at a top-tier university is quite different from providing topical security instruction to industry professionals and non-traditional students, who may or may not have strong technical backgrounds. Also, the desire to use the most appropriate and effective pedagogical practices in designing and delivering the course could potentially bump up against the constraints imposed by the use of an existing content delivery system.

This report outlines the results and challenges of this experiment. In the following section, the lecture-based version of the course is described. This version will be called the *traditional* course throughout this report, though it is more accurately "web-facilitated" according to the taxonomy of Allen and Seaman (from footnote 1) since the course syllabus, assignments and collateral materials were delivered online. Section III describes the modification of the course into a *blended* (or *hybrid*) version. By "blended" is meant that this version of the course was not developed exclusively for online delivery as might be expected in distance learning. Content delivery was primarily through an online system, but there was also a weekly in-class component and student assessments via programming assignments and exams. In section IV the Quest Learning and Assessment content delivery system is described. The results of student assessment and student responses to the blended course are described in section V. Pedagogical issues raised in this project are discussed in section VI. Issues relating to using this course development as a starting point for an industrial education course are discussed in section VII. Finally, lessons and conclusion of this study are described in section VIII.

II. The Traditional Course

The lecture-based Introduction to Computer Security course was originally developed and taught in 2003 in response to a perceived need for a security-related offering in UT's Computer Science curriculum. At that time, the Computer Science department contained several faculty whose research touched on security, but none with a primary focus on security. Since then, several prominent security researchers have joined the faculty, a security center has been established, and a suite of courses (including this one) were developed and accredited to satisfy the requirements for the CNSS Infosec Professional (4011) certification.

The author, a specialist in formal methods but with a long involvement in security research and secure system development, was tapped to develop an Introduction to Computer Security course and deliver it *the first semester*. He has taught it consistently ever since. The course has now been offered 16 times and remains one of the most popular upper-division electives in the UT CS curriculum.

UT Austin is semester-based. As a three credit hour course, the traditional class typically meets for 50 minutes three times a week for 15 weeks—around 35 hours of in-class instruction (not counting time for review and assessment). The course also has been taught twice in the summer, meeting for 5 1/2 weeks, five days a week for 75 minutes each day.

Though titled *Introduction to Computer Security*, this course could more accurately be labeled *Foundations of Computer Security*. The goal is to provide students with an understanding of the security problem and some of the fundamental tools and techniques useful for addressing it. Major topics include:

- Overview of the security problem
- Confidentiality policies
- Integrity policies
- Availability
- Basic information theory
- Cryptography
- Applications of crypto
- Cryptographic protocols
- Malware
- System certification

Though it has evolved considerably over time, the core content has remained consistent. As with any security-related course, it is a challenge to keep the material timely, because the discipline changes so quickly. One concern going into this project was that this tendency for the material to become stale would be exacerbated if

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the lectures were captured on video and not updated regularly. However, the fact that this course's material is intentionally foundational rather than bleeding edge promises a longer "shelf-life" for this course than might otherwise be expected for a typical security course, whether delivered in the traditional or an online format.

III. The Blended Course

During the summer of 2011, the course material was reformatted for online delivery. The topics and ordering of the traditional course were largely maintained, but somewhat streamlined. The course content was re-organized into 80 mini-lectures grouped into 17 modules. A typical module consists of 5–6 lectures and roughly corresponds to a single week of instruction in the traditional class. Modules were mapped onto the 14 weeks[2] of a standard long semester, with several short modules added to force module breaks at major topic boundaries. Figure 1 shows the lectures for the first five weeks (six modules) of classes.

The 80 mini-lectures were videotaped and edited by professional videographers at the facilities of the UT College of Natural Sciences during the summer and early fall of 2011. Lectures varied from 5–10 minutes in length and feature the instructor presenting several slides on a single topic. In addition to the videos, students have online access to an extended and elaborated version of all material from the slides, containing worked problems and supplementary material. Associated with each module is a series of short essay questions testing the student's mastery of the material.

A typical week's work for a student in the blended class involves viewing the videos in one or two modules and answering the questions. Quest allows the instructor to set and enforce deadlines for accessing modules. Students generally have access to a given module for a week before the material is first discussed in class, and are required to submit answers to questions by the end of the day that the material is first discussed, typically on Monday. Thus, if a student does not understand some material, he or she can get clarification prior to answering the questions.

Students are required to attend discussion sessions on Monday and Wednesday. (The traditional version of the class also would meet on Friday.) In-class sessions are devoted to reviewing briefly the content of the week's module(s), working problems, discussing the material, resolving misunderstandings, and potentially having a pop quiz to test the students' understanding of the material. These discussion sessions typically last about 30 to 40 minutes.

[2] There are actually 15 weeks in a long semester, but this allows a week for exams and review.

Lect	Mod	Wk	Title
01	1	1	Introduction
02	1	1	Why Security is Hard
03	1	1	Security as Risk Management
04	1	1	Aspects of Security
05	2	2	Policies and Metapolicies
06	2	2	A Policy Example: MLS
07	2	2	MLS Example: Part II
08	2	2	MLS Example: Part III
09	2	2	MLS Example: Part IV
10	2	2	Tranquility and BLP
11	3	3	Access Control Policies
12	3	3	Lattice-Based Security
13	3	3	Covert Channels I
14	3	3	Covert Channels II
15	3	3	Covert Channels III
16	3	3	Detecting Covert Channels
17	4	4	Non-Interference
18	4	4	Non-Interference II
19	5	4	What is Integrity?
20	5	4	Modeling Integrity
21	5	4	Biba's Strict Integrity Policy
22	5	4	Biba's Other Policies
23	6	5	Lipner's Model
24	6	5	The Clark-Wilson Model
25	6	5	The Chinese Wall Policy
26	6	5	Role-Based Access Control
27	6	5	Storing the ACM

Figure 1. Modules 1–6

In addition to the modules, students complete several programming assignments over the course of the semester. These are designed to reinforce the lecture content and to introduce new topics. Assignments vary each semester, but have included:

- building an access control system with a Bell and LaPadula (BLP) confidentiality policy;
- "breaking" their secure BLP system with a covert

channel;

- implementing a password cracking system;
- coding a Markov process to generate pronounceable passwords;
- implementing a subset of Unix file protection;
- coding the AES encryption algorithm in CBC (or other) mode;[3]
- implementing a Kerberos-like protection scheme.

Students are allowed to team with one other student on programs. Coding is done in Java, which is the primary programming language taught in earlier CS courses. Allowance is made for transfer students or non-majors who do not know Java to use a different language.

Finally, there are two major exams during the semester. A one-hour midterm exam is given as near as possible to the midpoint of the semester, but well before the semester deadline for dropping the class without academic penalty. A three-hour final exam is given during the regular finals period following the last day of class. Both are closed book exams, but a single sheet of notes is allowed.

Students also may interact with each other, the instructor and teaching assistant via a class newsgroup and mailing list, or visit the instructor or TA in their offices. (The author maintains an open door office policy.) There is no requirement that students avail themselves of these opportunities for interaction.

IV. QUEST

Quest Learning and Assessment [4] is a web-based content delivery system developed and maintained by the College of Natural Sciences at the University of Texas at Austin. Quest is widely used by math and science faculty at UT Austin as an auxiliary teaching technology. It accesses an extensive knowledge base of questions developed and submitted by faculty and supports randomizing question data, customizing flow depending on student responses, automatic grading and immediate feedback to the student. Faculty may also supply animations and videos that are hosted on the tool. At UT Austin, students in Quest-based courses are required to pay a semester fee of $22 for the use of the system. In addition to its use in Austin, Quest is used at more than 1000 high schools and colleges.

Prior to the current course, Quest apparently had not been used at UT Austin for the type of lecture-based course delivery described here. Faculty had used videos largely as supplemental material, not as a primary medium for delivering lectures. Also, the Quest learning assessment component previously was oriented toward multiple choice and short answer questions. The ability to handle essay questions was added to support this class. This permits more open-ended answers, but eliminates the possibility of automated grading, customized flow, and immediate feedback.

The blended course was facilitated but also somewhat constrained by the use of this existing content development system. The ability of Quest to host learning modules containing videos, questions and various supplementary materials was extremely useful. The Quest team was immensely helpful and responsive to requests for tweaks and additional functionality.

However, there were instances when the technology was limiting. For example, initially, questions were associated with each individual lecture rather than with an entire module. In that scenario, students objected to the amount of time and the number of mouse clicks necessary to access the questions multiplied by the large number of lectures. The TA objected to the large number of clicks needed on her part to access the answers. A partial solution was reached by grouping questions by module rather than by individual lectures. This alleviated the immediate problem, but from a pedagogical standpoint it was less than optimal as it meant that students typically did not confront the questions associated with an individual lecture until after they had viewed 5 or 6 lectures.

Also, at least initially, it was difficult for students to save their work and return; work was frequently lost. Eventually, the instructor duplicated the questions on a separate web page. Students were encouraged to answer them in a file and then copy and paste their answers into the Quest window.

The large number of essay responses placed a significant grading burden on the TA. This led to significant delays in feedback to the students. In retrospect, developing a suite of multiple choice or short answer questions would have better leveraged the capabilities and strengths of Quest. The author was uncertain whether such questions would

[3] Students often report that coding AES is the most useful programming project they complete during their undergraduate career. It is frequently listed on the resumes of graduating seniors.

Semester	Class Size	Midterm Exam	Final Exam	Class Average
Fall 2011	52	75.23	75.28	77.93
Fall 2010	58	82.42	75.17	82.58
Summer 2010	45	72.03	74.59	77.55
Spring 2009	39	76.13	77.89	77.26
Summer 2009	44	79.45	79.11	82.81
Spring 2008	34	78.24	75.42	81.32
Fall 2008	36	78.61	81.87	80.84

Figure 2. Grading Results for Recent Semesters

adequately test student learning for this material.

V. Results and Student Response

The semester began with an enrollment of 56 students; four students had dropped by the middle of the semester. The large class size and low drop rate are typical for this course.[4]

The obvious question is whether the blended approach proved more or less effective than the traditional approach to teaching this material. The independent variable in this case is the delivery modality; the dependent variable is student learning. However, the sample size is too small to draw any strong conclusions. Over the 16 times that this class has been taught, there is considerable variability from semester to semester affected by the student population, changes in course content, different programming assignments, extra credit opportunities, content of exams, and other factors.

Figure 2 lists normalized exam and class semester averages over several recent semesters. The Fall 2011 class is the blended class; the others are all traditional lecture-based versions. Exams were comparable in the blended and traditional class administrations. The class size listed is the number of students remaining at the end of the semester. Note that the scores in the blended class fall comfortably within the range of results for the traditional lecture class. This suggests that the blended format was neither a significant boon nor impediment to student learning.

[4]This class is very popular and is usually oversubscribed, meaning students join a waitlist to add the course in the event of a drop during the first few days of class. The class limit has been increased several times since the class was first offered in 2003. At that time the limit was 30.

Students were given the opportunity to offer suggestions or criticisms at various times throughout the semester. Specifically:

- students were invited to offer comments in class or via email at any time during the semester;
- a short survey eliciting the students' assessment of the blended format versus a traditional class format was administered two weeks before the end of the semester;
- students completed a standard, anonymous course evaluation in the last week of the semester.

Comments that students offered in class or via email generally regarded issues with the technology, not with the format of the class.

A short survey was distributed to students via email near the end of the semester. Students were asked to evaluate the blended delivery of the course content, and not to address in this venue issues with the course content, instructor, TA, assignments, etc. Those issues were fair game for the anonymous class evaluation. The survey asked the following four questions:

1. How did the blended format (videos and questions online, in-class discussions) work for you? Do you think it more, less or equally effective compared to a traditional lecture format?
2. Please comment on the use of Quest as a medium for content delivery.
3. Was the time commitment for this class more, less, or equal to other upper division CS electives you've taken?
4. Feel free to add any comments or suggestions for improving the delivery of the course content.

Students were requested, but not required, to respond to the survey via email. The responses were not anonymous.

Only 15 students responded to the survey. However, some common themes emerged.

- Response was uniformly favorable to the online components of the class. One student noted that one benefit was "the ability to replay the video; it allowed

me to view the material multiple times until I truly understood it." Students responding all rated the blended format as more effective or equally effective compared to a traditional course.

- Many students did not value the required in-class meetings. They generally felt that a single optional problem-solving session per week would have been adequate and preferable. On the other hand, a minority felt that the in-class sessions were useful in reinforcing the material.

- The time commitment was almost uniformly rated as equal to a traditional class. Only one student, an electrical engineering major who had not taken any other CS courses, rated the time commitment as lower than his regular classes.

- Students requested more timely feedback on the online questions. During the semester, the TA had been overwhelmed with the volume of work and grading of the online questions was delayed, sometimes for several weeks.

- Around half of the respondents reacted negatively to the use of Quest. Some found the system cumbersome and difficult to navigate. One student wrote: "I cannot believe we paid to play YouTube videos and answer text questions about them, and ultimately had to email the TA when Quest couldn't handle our submissions." Others were largely indifferent to the use of Quest as a vehicle for content delivery.

The class evaluation is a standard survey administered in every class during the final week. It is anonymous and taken by all students present on the day it is administered. Students are asked to respond on a scale of 1 (strongly disagree) to 5 (strongly agree) to a number of questions such as: course well-organized, instructor communicated information effectively, instructor showed interest in student progress, etc. These are averaged and reported on a 5 point scale. In addition, students provide an overall assessment (on the same scale) of the course and the instructor. Figure 3 provides the overall evaluations for the hybrid class and for the same six recent classes listed in Figure 2. Notice that the course rating for the hybrid course is somewhat lower than is typical, but the instructor rating is in line with previous semesters.

Semester	Course Rating	Instructor Rating
Fall 2011	3.8	4.2
Fall 2010	4.2	4.5
Summer 2010	4.4	4.7
Spring 2009	4.2	4.2
Summer 2009	4.2	4.4
Spring 2008	4.1	4.2
Fall 2008	3.6	4.2

Figure 3. Course Evaluations for Recent Semesters

VI. Pedagogical Issues

The statistics on the prevalence of distance and online learning cited in Section I show that online learning is coming whether or not institutions are ready for it. The goal of this experiment was understanding whether and how online education might be integrated into an existing curriculum while preserving quality.

Multiple guidelines and best practices for distance education exist [5]. The author consulted these prior to developing the blended course. However, the fit isn't exact. For example, distance learning typically assumes a geographically distributed student body and strives to create a learning community among individuals who may never meet each other in person. For this class, the students were primarily upper-division computer science students at the same university and often have taken multiple classes together. This obviates creating an artificial learning community in the class.

Research also suggests [6] that the successful development of an online class can benefit from teaming a subject matter expert with an instructional designer and a media specialist. This blended course development certainly benefited from close collaboration between the instructor and the Quest team, which includes videographers, editors, media specialists, etc. Still, the development was largely driven by the instructor and probably would have benefited from more intensional interaction specifically with an instructional designer with expertise in effective online education.

Surprisingly many studies (e.g., Russell [7]) have found that the choice of instructional media do not significantly affect learning, *assuming the course designer and instructor follow sound pedagogical practice*. Quality

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seems to be less about the media than about the teaching. Lacking prior expertise in developing online instructional materials, the author fell back on best practices for education in general. The "Seven Principles for Good Practice in Undergraduate Education," first published in 1987 by the American Association for Higher Education [8], have become a widely-adopted benchmark for quality undergraduate teaching. The principles are:

1. encourage student-faculty contact,
2. encourage cooperation among students,
3. encourage active learning,
4. give prompt feedback,
5. emphasize time on task,
6. communicate high expectations, and
7. respect diverse talents and ways of learning.

Faculty-student contact (1) was encouraged by the in-class meetings and by the author's "open door" office policy. Student cooperation (2) was fostered by in-class discussions, the class mailing list, and team programming on assignments. The assignments also supplied opportunities for active learning (3), allowing students to put into practice the principles they were learning in the class.

There were mixed results in providing prompt feedback (4); the in-class sessions provided the opportunity to resolve misunderstandings. Tests, quizzes and assignments were graded promptly; online questions were not. This needs to be addressed in future semesters.

Time on task (5) means fostering effective time management. This was accomplished by setting deadlines, enforcing a schedule and spacing assignments throughout the semester; this prevented students from falling significantly behind, a frequent problem with a more self-paced regime.

The basic high expectations (6) and learning goals for the online class are exactly those of the traditional class. The class covers a large number of challenging topics and proceeds quickly. Programming assignments are realistic and difficult.

Finally, the combination of online lectures, in-class discussion, supplemental materials, and programming assignments is intended to offer a variety of differing ways of learning the material (7).

VII. Moving Toward Industrial Education

Recall from Section I that one of the primary goals of this experiment was to use the move to blended delivery of the course as a first step toward developing an online security offering for IT industry professionals and non-traditional students. Similar courses are offered by a number of commercial vendors but also by universities. For example, Stanford's Computer Security Certificate program (see `scpd.stanford.edu/computerSecurity`) offers a number of short online courses taught by experts and the possibility of obtaining a security certificate from that premier academic institution. For universities, these courses promise an additional revenue stream and extend exemplary educational opportunities to the wider community.

E-learning programs at universities have not been an unvarnished success. Garon [9] notes that some "academic attempts at providing universities online have been marketing failures and academic distractions. ... [Some] famous universities have closed their virtual doors ... [while] others have dramatically downsized the attempt to provide online degrees." The goal of this particular effort, however, is not to provide an online degree, but a focused, topical introduction to selected security topics.

Migrating toward an online security offering for an industrial audience requires that:

- the content be useful and marketable to the target audience;
- the quality of instruction reflect favorably on the institution;
- the delivery be efficient and cost-effective for the institution;
- the delivery be suitable for and accessible to the target audience.

The face-to-face interactions of the blended class likely are not appropriate or feasible for a scenario in which interactions are largely asynchronous. The appropriateness of Quest as a content delivery vehicle for an online course of this type also would have to be evaluated.

Simply re-packaging course materials from the blended course likely would not be successful for an industrial environment. Hirumi [5] notes significant differences in "how education and industry view quality and approach e-learning." He notes that academic institutions evaluate courses in terms of effectiveness, efficiency and appeal. In contrast, industry concentrates more on "technical quality, reusability, and interoperability of learning objects, [and] improves quality by reducing variance around set standards." The effort developing the blended course has been useful in providing an alternative delivery modality for a university course, but the result is not clearly a step toward a viable online security course for an industrial audience.

VIII. Lessons and Conclusions

This paper describes an experiment in migrating an existing traditional computer security course to a blended delivery mode. From the perspective of offering a quality learning experience to CS majors, the blended course appears to have been a success. Students generally reacted favorably and learning, as measured by exams and course averages, was comparable to the traditional lecture class.

The major failing seems to have been that the move to online delivery was too tentative; the blended approach tried to maintain too much of the traditional class structure. For example, requiring twice-weekly in-class sessions was unpopular and probably did not contribute significantly to outcomes. Though student-faculty interaction is generally recognized as critical to class success, Simonson [10] has noted that interaction is not a "magic potion that miraculously improves distance learning," and in fact, "the forcing of interaction can be as strong a deterrent to effective learning [as] its absence."

The use of the Quest Learning and Assessment tool to support class delivery had both positive and negative aspects. After some changes, Quest provided adequate functionality to support delivery of the course. There were some weaknesses, however, and the fit was not perfect. The Quest team at UT Austin was very receptive to requests for changes supporting the course development. However, the situation might have been less positive if this experiment had been conducted at a different university, without a local Quest support staff.

The next iteration of this class (Summer, 2012) will attempt to benefit from these lessons. That class will rely more on the online delivery and less on face-to-face class meetings.

It is unclear how the lessons of this experiment will affect the move to an online course offering for an industrial audience. It certainly will require more than simply re-packaging the materials from the blended course. As was mentioned at the beginning of this report, charting the right course will require understanding more about what differs and *should differ* between traditional and distance education.

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